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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

A SYNTHESIS OF BOW WAVE PROFILE AND CHANGE OF LEVEL DATA FOR DESTROYER-TYPE HULLS WITH APPLICATION TO COMPUTING MINIMUM REQUIRED FREEBOARDS

by

Richard C. Bishop

and

N. K. Bales

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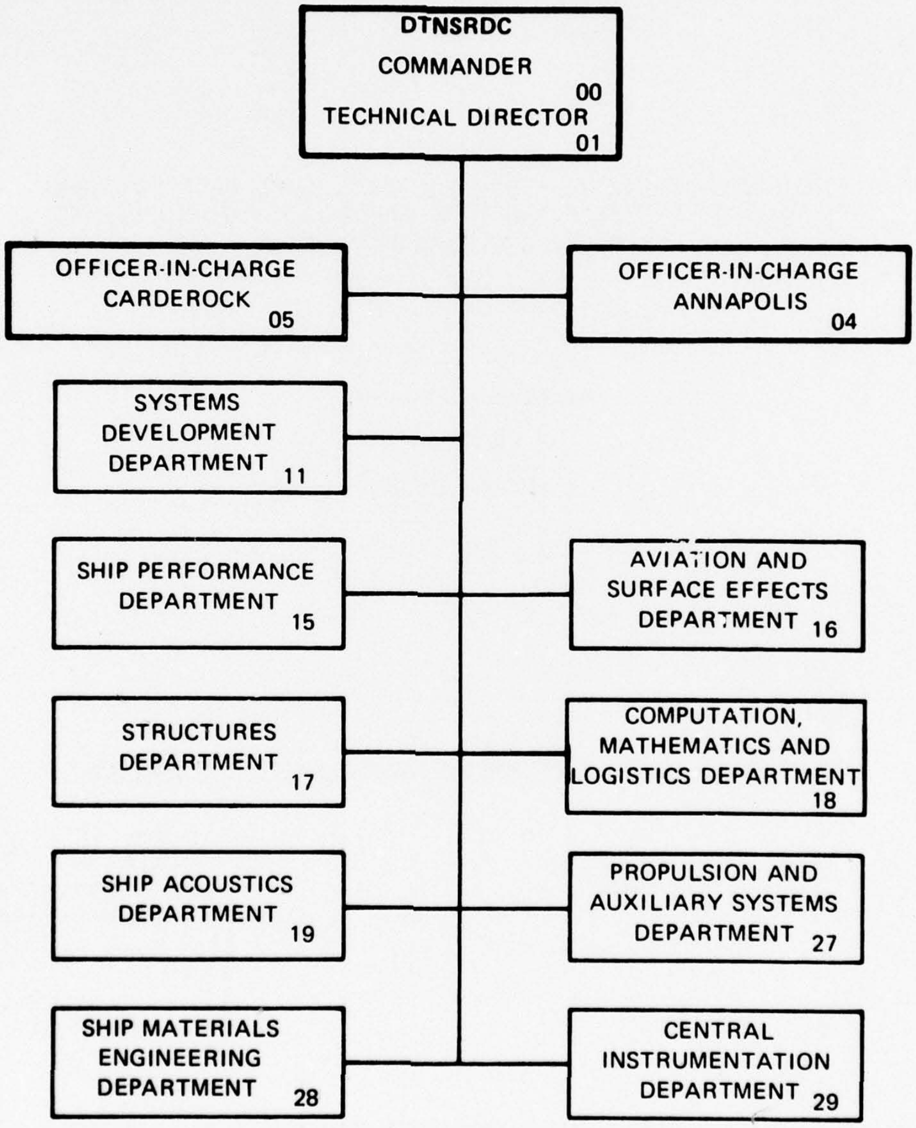

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Calm water measurements of change of level and of bow wave profile for 32 surface combatants are synthesized to derive empirical expressions for these phenomena. A distinction is drawn between ships with and without bow domes. The empirical expressions derived are found to be adequate for use in computing minimum required design freeboards.

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NOTATION

L	Ship length
V	Ship speed
x	Distance from forward perpendicular
δT	Sinkage
δT_B	Change of level at bow
δT_S	Change of level at stern
ζ	Bow wave profile elevation
θ	Trim

Subscrips 0, 1 and 2 indicate specific values of a variable

ABSTRACT

Calm water measurements of change of level and of bow wave profile for 32 surface combatants are synthesized to derive empirical expressions for these phenomena. A distinction is drawn between ships with and without bow domes. The empirical expressions derived are found to be adequate for use in computing minimum required design freeboards.

ADMINISTRATIVE INFORMATION

The work described herein was funded by the Conventional Ship Seakeeping Research and Development Program. This program is identified by Task Area SF 43411212 and Element Number 62543N. At the David W. Taylor Naval Ship Research and Development Center, where the work was performed, it was identified by Segment 20 of Work Unit Numbers 1-1504-100 and 1-1504-200.

INTRODUCTION

A design procedure for minimum required freeboard recently developed at the David W. Taylor Naval Ship Research and Development Center requires users to supply dimensional bow wave profile and change of level data. For greatest accuracy, it is suggested that this data be obtained from measurements for a hull similar to the one under investigation. A considerable amount of time and effort can be expended in pursuit of these supportive variables. It was, therefore, decided to develop some generalized analytical expressions for bow wave profile and change of level which could be used as input to the minimum required freeboard design procedure.

The expressions were developed by synthesizing measured bow wave profile and change of level data. Attention was restricted to surface combatants since this is the only class of ships for which the minimum freeboard procedure has been implemented in detail. This report describes the data synthesis effort and the results thereof.

THE DATA BASE

The data base employed consisted of bow wave profile and change of level data measured in calm water for 32 destroyer and cruiser models. The ships ranged in length from 116 meters to 213 meters. Change of level data were

typically available for ship speeds up to 35 knots. Bow wave profile data were generally available for high speeds, e.g., 30 knots; but were available for only a few ships at lower speeds. Hull forms were mostly of conventional destroyer type, but a few experimental variants were included.

Change of level data were broken-out into their trim and sinkage components as it was thought that these components had independent physical significance; and thus, offered a better possibility for successful synthesis than change of level per se.

DATA SYNTHESIS

Current methods used in the minimum freeboard procedure for transforming the dimensional bow wave profile and change of level data for a similar ship to the ship size and speed(s) of concern were taken as a basis for the data synthesis. Thus, Froude scaling was used to reduce all data to a common ship length. Then the bow wave profile data were further transformed in accord with simplified versions of the formulas developed in reference 1.*

Preliminary results indicated that large bow domes had a major impact on the data under consideration. Hence, ships with and without bow domes were treated separately. In this context, it should be noted that 18 of the 32 ships evaluated had bow domes.

The change of level and bow wave profile analyses are described independently in the following sections.

CHANGE OF LEVEL

Trim and sinkage were simply Froude scaled to a common length, L_o, which represented the modal ship length of the sample population. Thus, a ship of length L which experienced sinkage δT and trim θ at speed V was assigned sinkage

$$\delta T_o = \delta T(L_o/L) \tag{1}$$

---

*Ogilvie, T.F., "The Wave Generated by a Fine Ship Bow," University of Michigan Report No. 127 (Oct 1972).

and trim

$$\theta_o = \theta \tag{2}$$

at speed

$$V_o = V\sqrt{L_o/L} \tag{3}$$

Plots of δT_o and θ_o versus V_o are presented in Figures 1 through 4. In these figures, δT_o is taken positive down and θ_o is taken positive bow up. The fair curves shown in the figures were fitted to the data using a least squares procedure.

For trim of ships with domes (Figure 1), the least squares line for $V_o \geq 10$ knots is

$$\theta_o = (1.5422X10^{-2})V_o - (2.1752X10^{-3})V_o^{\ 2} + (5.9570X10^{-5})V_o^{\ 3} \tag{4}$$

For $V_o < 10$ knots, θ_o is taken equal to zero.

The corresponding result for ships without domes (Figure 2) is

$$\theta_o = (9.2648X10^{-3})V_o - (1.5692X10^{-3})V_o^{\ 2} + (4.2912X10^{-5})V_o^{\ 3} \tag{5}$$

for $V_o \geq 7.5$ knots and $\theta_o = 0$ for $V_o < 7.5$ knots.

The least squares line for sinkage of ships with domes (Figure 3) is

$$\delta T_o = (2.392X10^{-3})V_o + (4.026X10^{-4})V_o^{\ 2} \tag{6}$$

while that for ships without domes (Figure 4) is

$$\delta T_o = (-1.613X10^{-3})V_o + (5.654X10^{-4})V_o^{\ 2} \tag{7}$$

Equations (4) through (7) apply to a ship length of 146 meters.

These results can be combined to obtain the change of level data required as input to the design procedure for minimum freeboard. For the ship of

length L_o, let δT_{Bo} be change of level at the bow and δT_{So} be change of level at the stern, and assume that the longitudinal centers of buoyancy and flotation both lie amidships.

Then,

$$\delta T_{Bo} = \delta T_o - (L_o/\delta T_o) \sin \theta_o \tag{8}$$

and

$$\delta T_{So} = \delta T_o + (L_o/\delta T_o) \sin \theta_o \tag{9}$$

where both δT_{Bo} and δT_{So} are taken positive up.

BOW WAVE PROFILE

Initially, the validity of the modified reference 1 equations in predicting changes in bow wave profile with changes in ship speed was explored. These equations are

$$x_2 = (V_2/V_1)^{3/2} x_1 \tag{10}$$

and

$$\zeta_2 = (V_2/V_1)^{5/4} \zeta_1 \tag{11}$$

where, at ship speed V_1, x_1 is the ship location at which the height of the bow wave profile is ζ_1 and x_2 and ζ_2 are the corresponding quantities at ship speed V_2.

In these equations, x is measured from the forward perpendicular, and ζ is taken positive upward from the load waterline. Typical results of these computations are shown in Figure 5.

Next, the bow wave profile data set was transformed using Froude scaling and equations (10) and (11). A typical ship length, L_o, of 146 meters was selected, and the bow wave profile (height ζ as a function of location x) at speed V for each ship of length L was scaled to length L_o using

$$\zeta_o = \zeta (L_o/L) \tag{12}$$

$$x_o = x\,(L_o/L) \tag{13}$$

and

$$V_o = V\sqrt{L_o/L} \tag{14}$$

Then equations (10) and (11) were applied with V_o taken equal to 25 knots. The latter ship speed was considered to be typical of the data base.

Figure 6 presents least squares curves fitted to the bow wave profile data treated as described above. The equations of these curves are

$$\zeta_o = (-2.034\text{X}10^{-2})(x_o-38.1) + (3.104\text{X}10^{-3})(x_o-38.1)^2 + (1.820\text{X}10^{-6})(x_o-38.1)^3 + (-1.653\text{X}10^{-6})(x_o-38.1)^4 \tag{15}$$

for ships with bow domes and

$$\zeta_o = (-2.699\text{X}10^{-2})(x_o-38.1) + (5.794\text{X}10^{-3})(x_o-38.1)^2 + (1.738\text{X}10^{-4})(x_o-38.1)^3 + (5.732\text{X}10^{-7})(x_o-38.1)^4 \tag{16}$$

for ships without bow domes. These equations apply to a ship length of 146 meters and to a ship speed of 25 knots. For x_o > 38.1 meters, ζ is taken equal to zero.

APPLICATION OF RESULTS

The generalized change of level and bow wave profile results represented by equations (4) through (9), (15) and (16) can, together with their associated ship length and ship speed parameters, be used as input to the minimum required freeboard design procedure. This procedure essentially reverses the steps taken to obtain the results given here. To obtain change of level estimates for a ship of length L at speed V, the generalized change of level results for the 146 meter ship are Froude scaled to the specified L and V. In the case of bow wave profile, the generalized results for the 146 meter ship at 25 knots are first Froude scaled then transformed in accord with equations (10) and (11)

to account for the shift in bow wave profile crest which occurs with ship speed. A distinction must, of course, be made between ships with and without bow domes.

DISCUSSION

The results obtained here are obviously crude in the sense that they do not recognize differences in hull form beyond the presence or absence of a bow dome. As a result, there is a great deal of scatter about the typical results derived. The worst comparisons are, however, those involving unusual hull configurations and/or extremely high speed. For conventional hulls at moderate speeds the generalized results are thought to be of sufficient accuracy to be commensurate with the earlier stages of the ship design process.

CONCLUSION

When the constraints of the design process do not admit a search for data on a similar hull, the generalized change of level and bow wave profile results given here are sufficiently accurate to be used in conjunction with the minimum required freeboard design procedure for conventional surface combatants at moderate speeds.

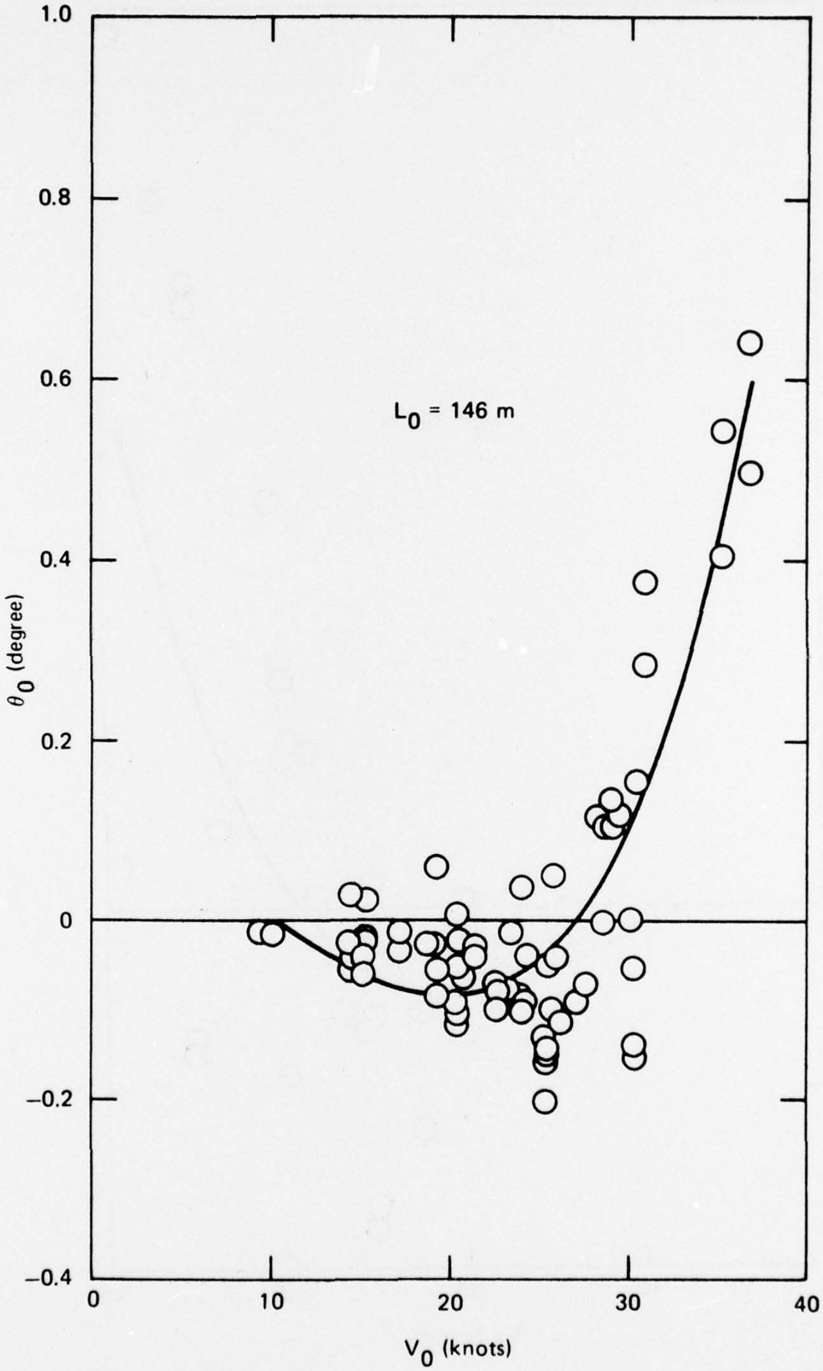

Figure 1 - Trim versus Ship Speed for Ships with Bow Domes

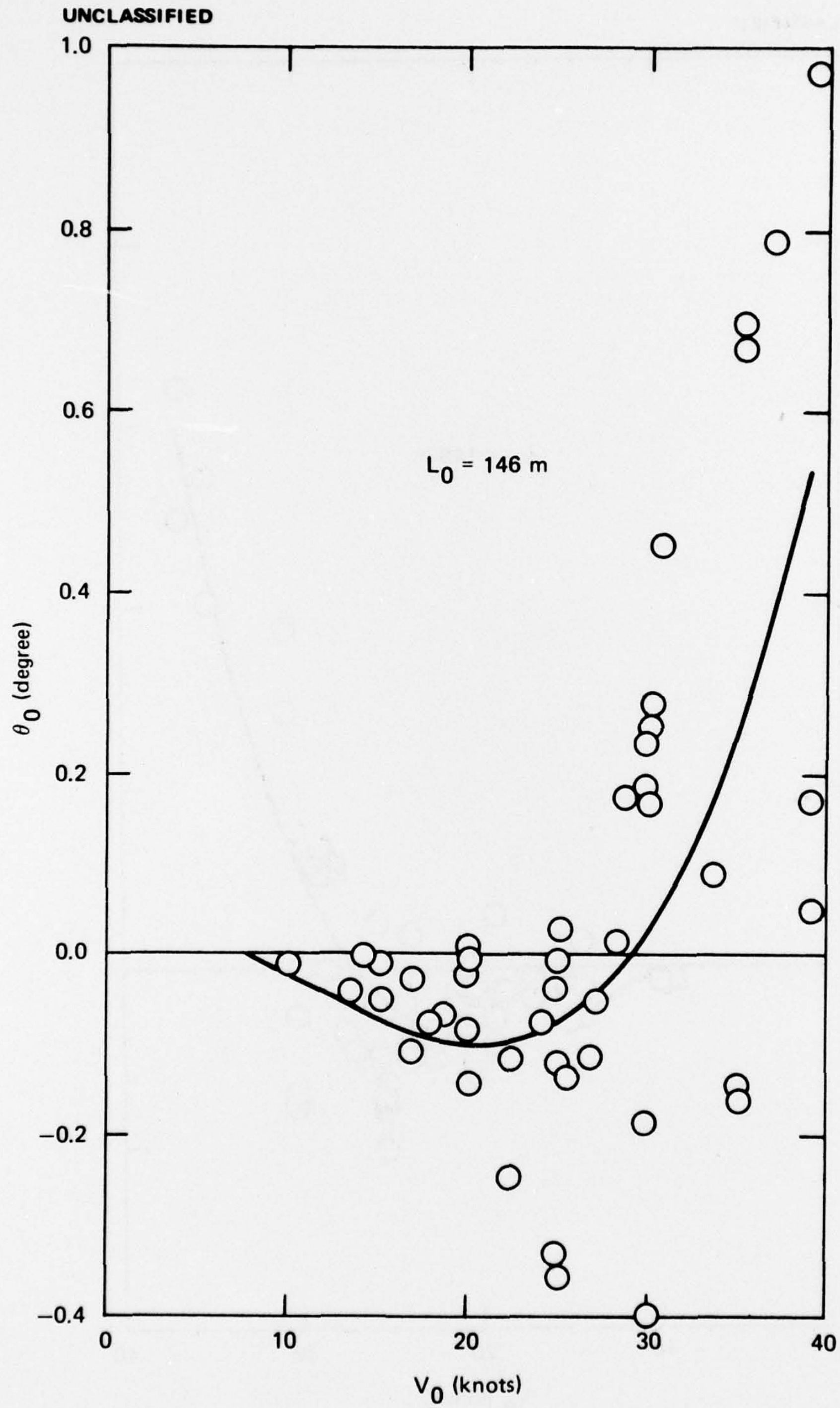

Figure 2 - Trim versus Ship Speed for Ships without Bow Domes

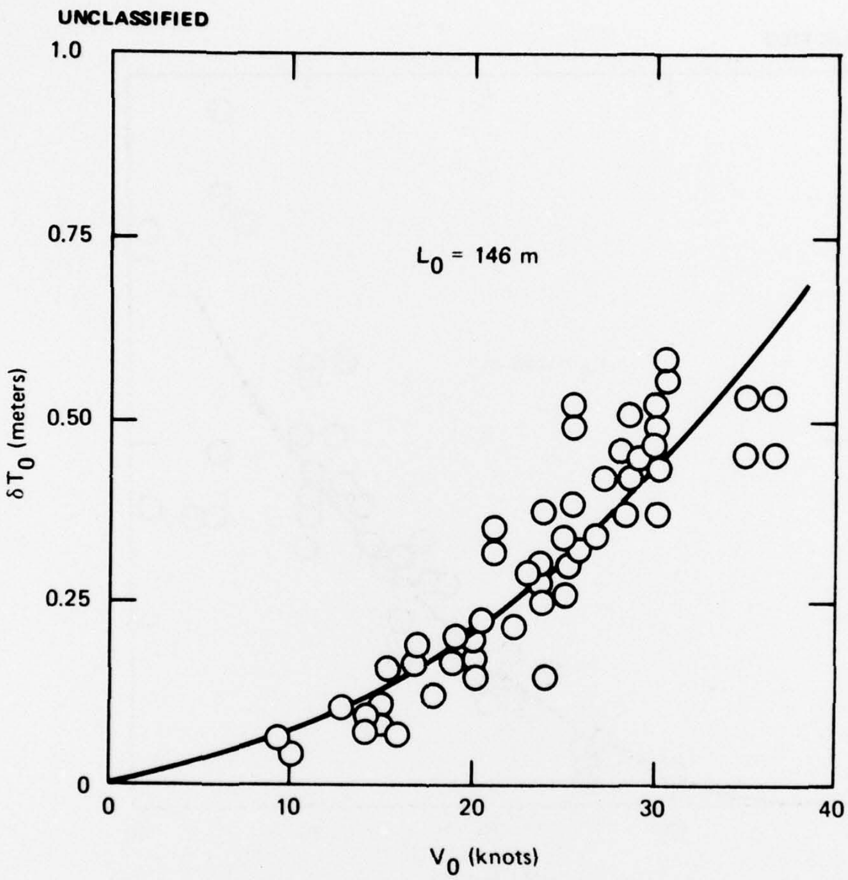

Figure 3 - Sinkage versus Ship Speed for Ships with Bow Domes

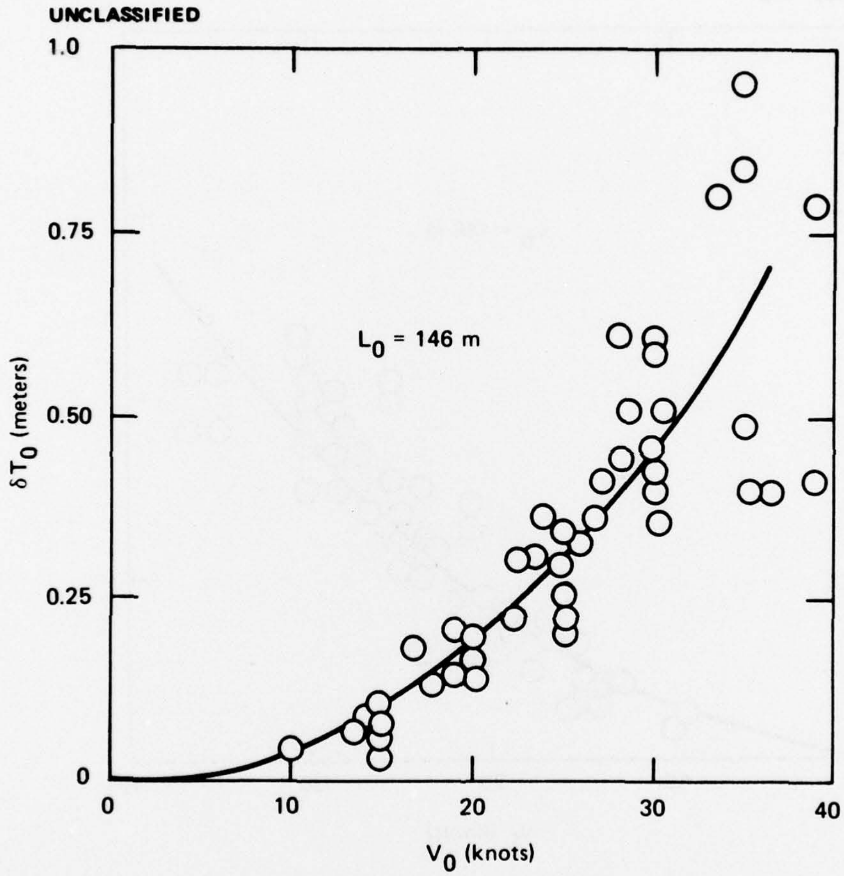

Figure 4 - Sinkage versus Ship Speed for Ships without Bow Domes

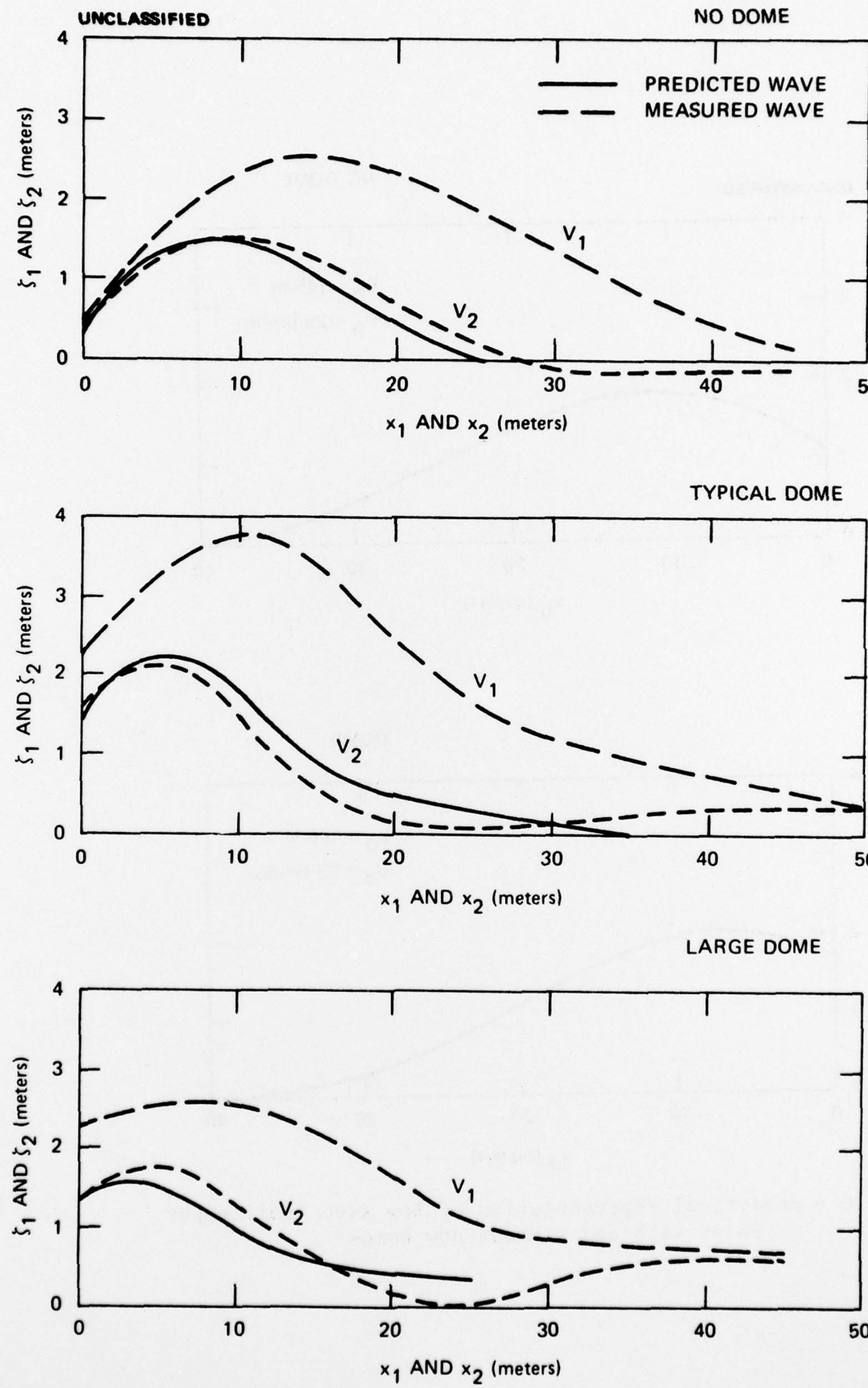

Figure 5 - Bow Wave Profile Transformation with Ship Speed

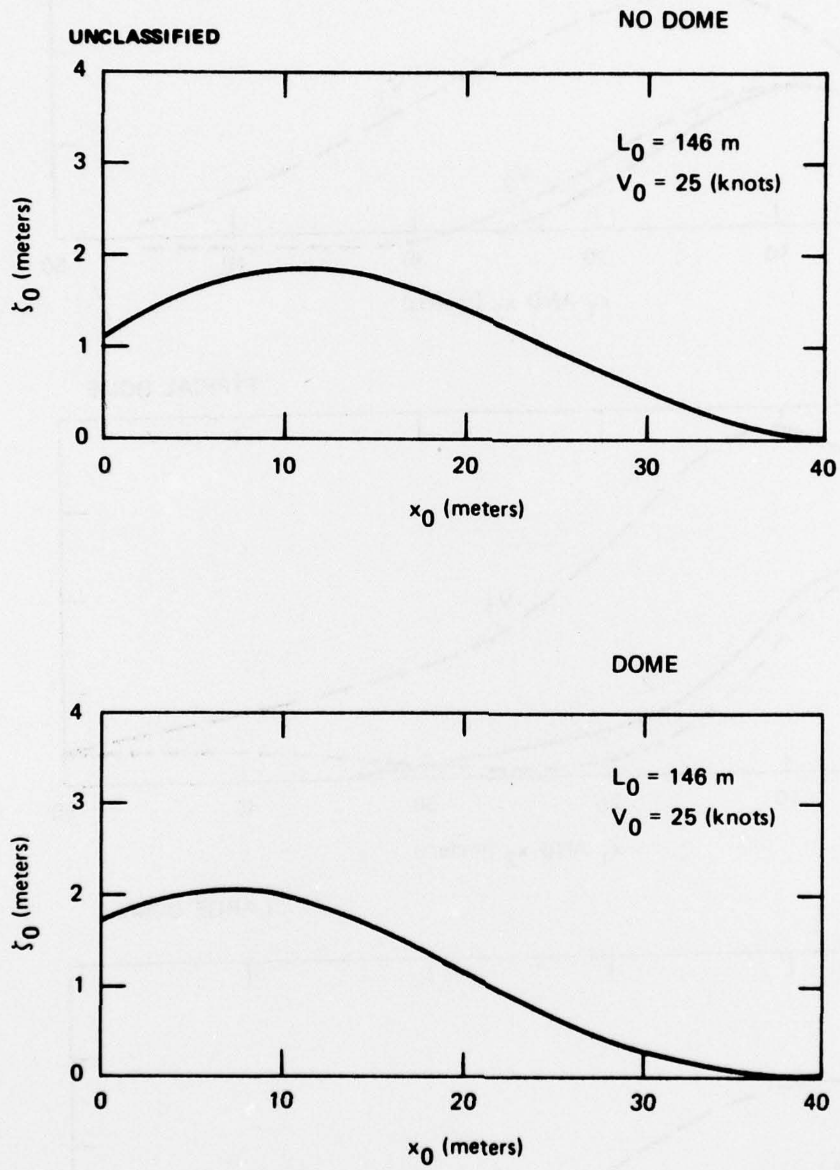

Figure 6 - Analytical Representation of Bow Wave Profile for Ships with and without Bow Domes

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